1.0 INTRODUCTION

The California State Lands Commission (CSLC) is evaluating removal options for shell mounds at the sites of four previously decommissioned offshore oil and gas platforms - *Hilda*, *Hazel, Hope,* and *Heidi* (i.e., the 4H Platforms) - in the Santa Barbara Channel (Figure 1-1). Prior to platform removal, shell debris and other drilling-related solid wastes accumulated below the platform structures, creating large mounds on the seafloor. Previous testing indicated that concentrations of several metals and petroleum and chlorinated hydrocarbons were elevated in the shell mound sediments. Therefore, an important consideration for evaluating removal options is whether and to what extent contaminants associated with the shell mounds are leaching or remobilized to overlying waters and the long-term risks to water quality and biological resources. A separate issue related to the possible spreading in-place or knock-down removal option is the similarity of the physical (sediment texture) and chemical characteristics of the mound materials to those of bottom sediments in areas adjacent to the mounds.

CSLC contracted Science Applications International Corporation (SAIC) to conduct a water quality study, using caged mussels (i.e., *in situ* field bioassay) and semi-permeable membrane devices (SPMD), at the shell mounds and appropriate reference sites that would provide the information needed to evaluate these removal options. Additionally, SAIC investigated surficial sediment quality in the vicinity of the shell mounds to evaluate the similarities in the chemical and physical characteristics of the adjacent bottom sediments with those of the shell mound materials. The results of these studies are presented in this report.

1.1 BACKGROUND

Production by Chevron of oil and gas reserves within State Leases PRC 1824 and PRC 3150 (in the eastern portion of the Santa Barbara Channel offshore Santa Barbara County) began in 1958 with the installation of Platform Hazel. Construction of Platform Hilda was completed in 1960, followed by Platforms Hope and Heidi in 1965. Hazel and Hilda were installed approximately 1.5 nautical miles (nm) offshore Summerland at water depths of 96 feet (29 meters [m]) and 106 feet (32 m) respectively; Hope and Heidi were located approximately 2.6 and 2.5 nm offshore from the city of Carpinteria, and about 3 nm southeast of Hazel, at water depths of 137 feet (42 m) and 126 feet (38 m), respectively. Oil and gas production from the 4H platforms was transported by subsea pipelines to Chevron's onshore processing facility located in Carpinteria (which is now owned and operated by Venoco, Inc.). During operation, the four platforms produced an estimated 62.3 million barrels of crude oil and 132.8 million cubic feet of gas.

Prior to the 1969-1976 State moratorium, used drilling muds (or fluids) and cuttings were discharged from oil and gas platforms and accumulated beneath the platforms. From 1976 until drilling ceased, drilling muds and cuttings were collected at the platforms, transported in bins to shore, and hauled to a disposal site (pers. comm., K.M. Light, Chevron). Information concerning the volumes and composition of drilling muds

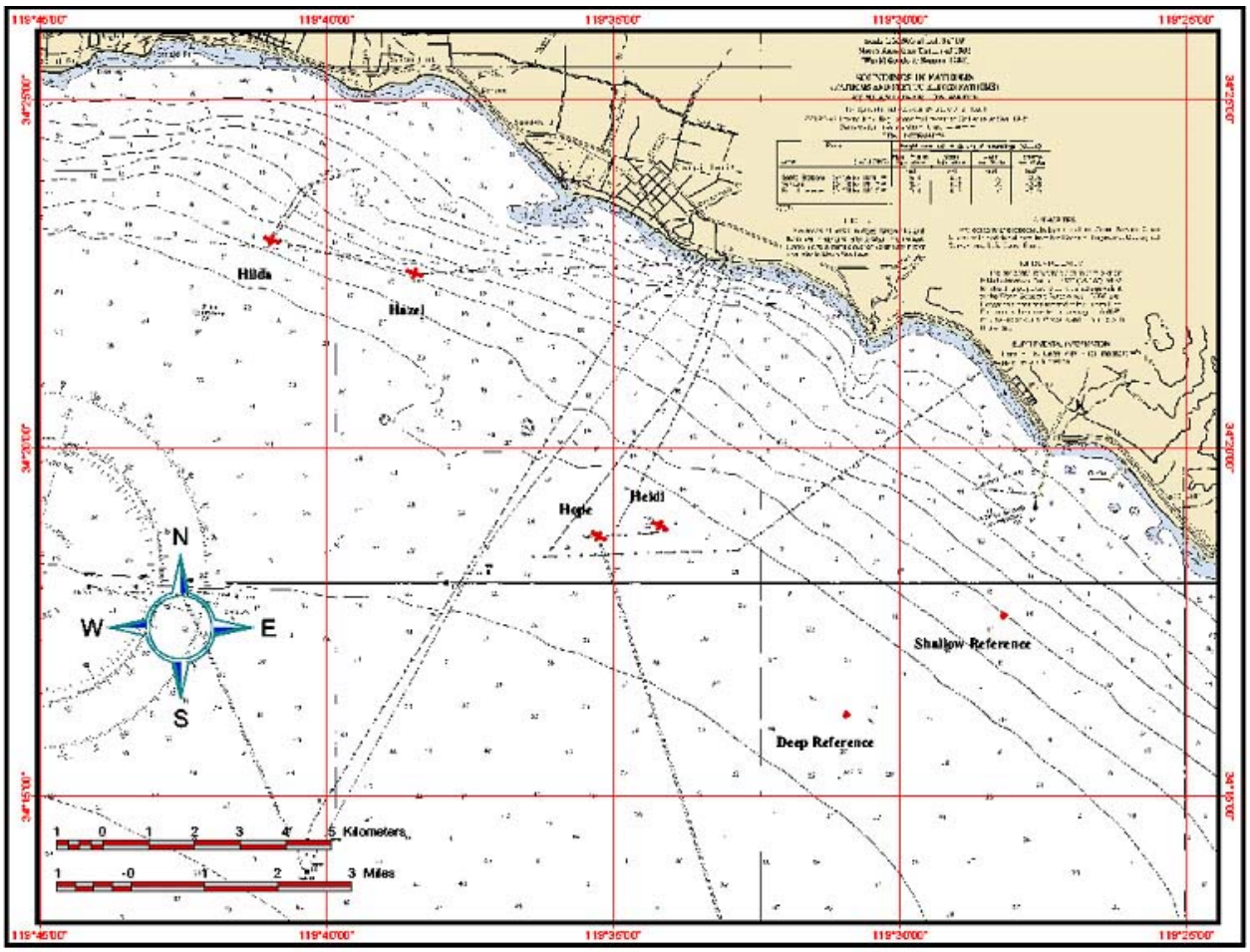

Figure 1-1. Chevron 4H Shell Mounds and Reference Sampling Locations

and cuttings discharged from the 4H platforms prior to 1976 was not available. Typical well drilling operations generate approximately 200 to 1000 metric tons (MT) of drilling mud solids and a similar amount of cuttings (Neff, 1987). A review of drilling logs for the 4H platforms (O'Reilly, 1998) noted that both water-based and oil-based muds were used during drilling, although oil-based muds were used infrequently. Cuttings are pieces of formation rock that are produced during drilling, and they are typically considered chemically inert, although cuttings can transport drilling muds and/or formation oils that are not completely removed during the cuttings washing process prior to discharge.

All of the wells on the 4H platforms were shut-in prior to September 1992. In 1994-1995, the CSLC and the California Coastal Commission (CCC) approved the decommissioning of all four platforms following adoption of a Mitigated Negative Declaration (MND No. 652, CSLC 1994) and coastal development permit (CDP) E-94-006, respectively. In 1996, Chevron removed most of the platform structures except for the four, 27-foot (8-m) diameter, Platform Hazel caissons.

While they stood, the 4H platforms provided a substrate for the attachment of mussels and other sessile invertebrates and algae, and supported associated fishes and mobile invertebrates (Page and Dugan 1999; Holbrook et al. 2000). The biotic community of the platforms produced a steady rain of shells and organic matter that, along with the accumulated drilling muds and cuttings and naturally deposited sediments, formed "shell mounds" under each of the four platforms. Based on studies conducted at Platform Eva off Huntington Beach, CA, Wolfson et al. (1979) estimated that approximately one cubic meter (1 MT) of mussels fall from the platform each day. The 4H shell mounds are roughly semi-circular, approximately 25 to 28 feet (7.6 to 8.5 m) in height, with diameters ranging from 180 to 266 feet (55 to 81 m). The bathymetry of each shell mound and the surrounding seafloor is shown in Figure 1-2. A total volume of approximately 45,000 cubic yards (34,405 m^3) of material is contained in all four mounds.

1.2 PREVIOUS INVESTIGATIONS AT THE 4H SHELL MOUNDS

Physical and biological characterizations of the 4H shell mounds were undertaken during 1998-2003 (Table 1-1). This work included high-resolution bathymetric surveys of the mounds conducted by Fugro, Inc., a biological habitat characterization study (de Wit, 1999), and a more comprehensive follow-up study (de Wit, 2001). The objectives of the latter study were to: (1) collect and analyze data on the physical, chemical, and biological characteristics of the shell mounds; (2) identify feasible methods of removing the features; and (3) assess potential impacts to various resources from shell mound removal and from their continued existence in-place. The de Wit (2001) report (available on the CSLC website at www.slc.ca.gov/ Reports/Reports.htm) concluded the following:

- With the exception of caisson structures remaining at the platform Hazel site, the shell mounds at all four sites have similar physical characteristics comprising three distinct strata: an upper layer of shells, an intermediate layer of drilling muds and cuttings, and an underlying layer of "native" seafloor sediments (Table 1-2).
- An oily sheen and petroleum odor were present in different layers at all shell mounds.

  The highest concentrations of several metals, total recoverable petroleum hydrocarbons (TRPH), polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs) in some shell mound strata, including the natural sediments underlying the shell mound material, exceeded those in the reference sediments.
- Elevated concentrations of selected contaminants in sediments and sediment elutriates (aqueous extracts) indicated potentials for acute toxicity to marine organisms.
- Shell mound-associated biota appeared to have decreased in species richness and abundance since removal of the platforms. The shell mounds in their current form (absent the platform structures) provide limited biological habitat value.

Table 1-1. Summary of Shell Mound Surveys

Survey/Plan	*Survey Description*
de Wit (1999)	Biological habitat characterization study using video and still photography from a remotely operated vehicle (ROV), along with diver observations and collection of macroinvertebrates.
de Wit (2001)	Biological data collected by ROV video and still cameras, physical and chemical characteristics assessed from the analyses of cores taken at several locations on each shell mound, and impact assessment based on the characteristics of feasible removal methods and on the results of the analyses of the site-specific data.
Fugro, Inc. (2002)	High-resolution bathymetric surveys of the shell mounds.
MEC (2002)	Chevron-commissioned investigation of contaminant bioaccumulation in organisms that occur on or near the shell mounds.
AMEC (2002a,b)	Vibracore collection of sediment cores from four locations on each of the four shell mounds, with the sediment cores from each mound subdivided into three strata and composited for analytical purposes; comparison with a sample from the LA-2 ocean disposal site reference location; and standardized analyses of sediment chemistry, toxicity, and bioaccumulation.
SAIC (present study)	Placement of caged mussels and semipermeable membrane devices in replicate groupings at each of the four shell mounds and at offsite "control" locations to evaluate water quality, plus deployment of current meters to measure the direction and strength of currents; chemical and grain size analyses of surficial sediments near each of the shell mounds to determine similarities with the shell mound material.

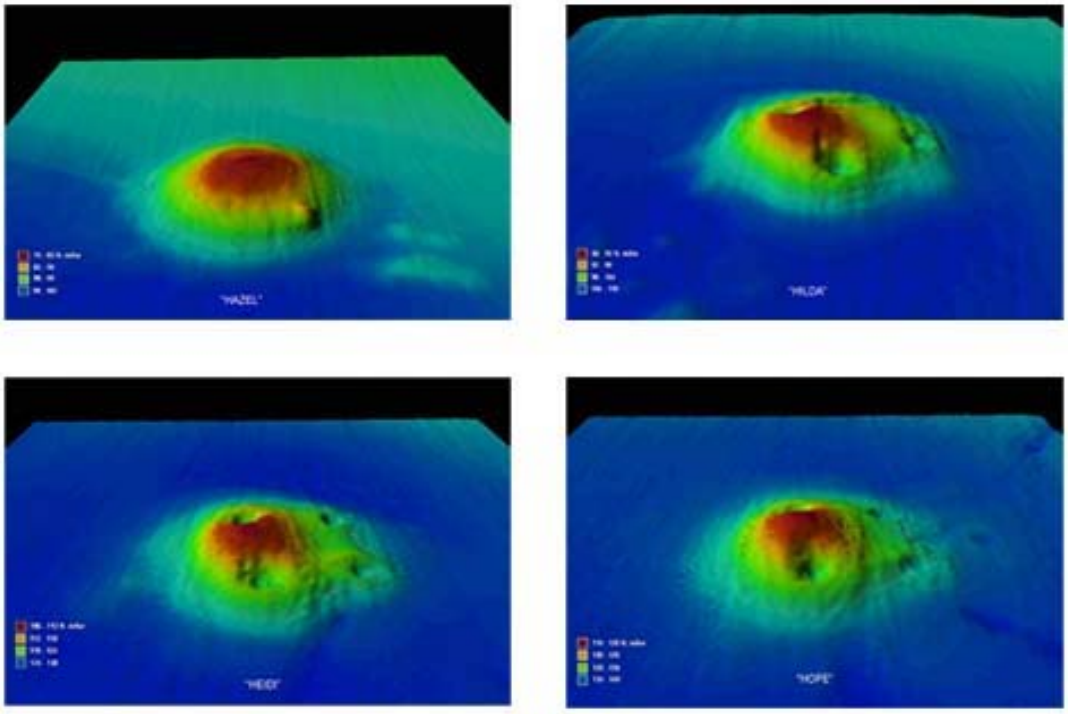

Figure 1-2. Bathymetry at the 4H Shell Mounds

Table 1-2. Summary of Shell Mound Strata

Strata	*Subdivision*	*General Description*	*Stratum Thickness in Vibracore in feet (m)*
1) Shell Hash	1a: Primarily shells with minor amounts of clay. 1b: Approximately equal mixture of shells and clay.	Mussel, clam, and barnacle shells up to several centimeters in diameter with variable amounts of black clay infilling.	1 to 7 (0.3 to 2.1)
2) Drill Cuttings	2a through 2e (as necessary) subdivided into distinct pockets of cuttings.	Inter-layered sandy lean [(1)] to fat [(2)] clay (CL/CH), and clayey to silty sand (SC/SM) with variable amounts of gravel-size siltstone rock fragments, with pockets of oil sheen/petroleum odor.	0 to 18 (0 to 5.5)
3) Sea Floor Sediments	Fairly uniform clay, no subdivisions.	Lean to fat clay (CL/CH), olive gray, medium stiff to stiff, with small shell fragments.	0 to >10 (0 to >3.1)

Notes:
[(1)] Lean = low plasticity
[(2)] Fat = high plasticity
Source: de Wit (2001)

In 2002, the CSLC directed additional investigation of the physical and chemical properties of the shell mounds to evaluate the potential suitability of the shell mound materials for disposal at a designated ocean dredged material disposal site. This investigation used a vibracore to collect cores from the shell mounds, and sediments were tested for physical and chemical properties, toxicity, and potential for contaminant bioaccumulation. The sampling and analysis plan (SAP) prepared by AMEC and SAIC (AMEC 2002a) for this investigation was consistent with the requirements of the USACE and the U.S. Environmental Protection Agency (USEPA) because these agencies regulate the disposal of dredged sediment in the ocean. Specifically, the SAP provided sampling and analytical procedures that were based on the USEPA/USACE procedures outlined in the *Evaluation of Dredged Material Proposed for Ocean Disposal* (Green Book) (EPA/USACE 1991) and the *EPA Region 9 General Requirements for Sediment Testing of Dredged Material Proposed for Ocean Dumping* (EPA 1989) that meet California Ocean Plan and Regional Water Quality Control Board (RWQCB) requirements. In April 2002, the CSLC, CCC, USACE, USEPA, and Central Coast RWQCB approved the SAP. The approved SAP included the following:

- vibracore collection of sediment cores from four locations on each of the four shell mounds, with the sediment cores from each mound subdivided into three strata and composited for analytical purposes;
- comparison with a sample from the LA-2 ocean disposal site reference location as required for consideration of disposal at the LA-2 disposal site; and
- standardized analyses of sediment chemistry, toxicity, and bioaccumulation.

Vibracore sampling of the mounds was conducted in May 2002. In August 2002, AMEC (2002b) completed a draft final report on the analytical results. The CSLC distributed this draft report to regulatory agencies and other interested parties for comment prior to its finalization. Key findings are summarized below.

Chemical analyses of sediment cores performed by AMEC (2002b), under contract to SAIC, confirmed the presence of elevated contaminant concentrations at all four of the shell mounds as described by deWit (2001). Concentrations of barium, which is a key constituent of drilling muds, were especially elevated in the top and middle strata of all four mounds, while concentrations in the bottom strata are considerably lower but variable. Concentrations of chromium, which is typically associated with certain drilling mud additives (chrome or ferrochrome lignosulfonate) were elevated primarily in the middle strata at each of the shell mounds. Lead concentrations were elevated in the middle strata at three of the mounds and, to a lesser extent, in the surface strata at two mounds. Zinc concentrations were elevated in both the surface and middle strata at all four shell mounds. Nickel and vanadium, which are components of crude oil, also co-varied in the sediments and occasionally were at elevated concentrations. Petroleum hydrocarbons (measured as TRPH, normal [saturated] alkanes, volatile organic compounds, and polycyclic aromatic hydrocarbons) were present at highest concentrations in the middle strata of all four mounds, while concentrations in the surface and bottom strata were comparatively lower. Unusually high concentrations (up to several parts-per-million) of a number of volatile organic compounds, especially

benzene, alkyl-substituted benzenes, toluene, xylenes, and naphthalene were present in the middle strata samples. Unlike most metals and chlorinated hydrocarbons, these compounds are relatively soluble in seawater and, therefore, typically do not persist in marine sediments. The presence of these volatile organic compounds in the middle strata samples was consistent with visual observations and core logs noting the presence of petroleum in the sediment cores. Polychlorinated biphenyls (PCBs) were also present at elevated concentrations (up to 1.6 parts-per-million) in sediments from three of the four mounds (Hope, Hazel, and Hilda), with the highest concentration in the surface strata from the Platform Hope mound.

Results of the toxicity and bioaccumulation tests generally were consistent for each of the 4H shell mounds. Shell mound sediments caused significant acute toxicity to test organisms (amphipods and mysid shrimp). In contrast, the suspended particulate phase exposures did not cause significant toxicity in mysids or silversides. Test organisms exposed to the shell mound sediments for periods of 28 days also exhibited significant bioaccumulation of barium and PAHs compared to organisms exposed to reference sediments (from the LA-2 ocean dredged material disposal site reference location). Based on the results from these sediment testing procedures, the shell mound materials would be considered unsuitable for placement at a designated ocean dredged material disposal site.

During 2001, selected macroinvertebrate species were collected by MEC (2002) from each of the 4H shell mounds and two reference sites, and soft tissues and whole organisms were analyzed chemically for evidence of contaminant uptake from the shell mound sediments. Red and yellow rock crabs (*Cancer antennarius* and *C. anthonyi*, respectively) collected at the shell mounds contained significantly higher concentrations of several metals, especially nickel and zinc, compared with reference site specimens, whereas no significant differences in tissue concentrations of any organic contaminants (e.g., petroleum or chlorinated hydrocarbons) were observed. While these results indicated some differences between the shell mound and reference site tissue burdens, they did not suggest widespread accumulation of contaminants by macrofauna potentially resident on the shell mounds. Differences between this study and the AMEC (2002b) sediment testing likely reflected several factors, such as: (1) species used for the MEC study are mobile and their exposure histories (i.e., residency) and equilibrium status relative to exposure conditions are unknown; and (2) sediment quality and, therefore, exposure conditions on the exterior portions of the mounds as characterized by the MEC study may be considerably different from those in the inner portions of the mounds, which were characterized by the sediment testing study.

1.3 REPORT ORGANIZATION

This report presents the results and findings of a water quality and sediment quality study conducted during 2003 at the 4H shell mounds. Section 2 describes the methods and materials used to conduct the study. Section 3 describes the results of the caged mussel and SPMD deployments, current and water temperature measurements, and grain size and chemical characterizations of surface sediments near the 4H shell mounds. Sections 4 and 5 present a discussion of the key findings and conclusions,

respectively. Appendices 1 through 5 contain the Sampling and Analysis Plan, report from Applied Biomonitoring, tissue chemistry data and QA narrative, SPMD chemistry data and QA narrative, and sediment chemistry data and QA narrative, respectively.